

VIRTUAL HUMAN HIP JOINT OBTAINED FROM CT IMAGES AND FEM TEST

Abstract: Hip joint is one of the most complicated in the human body. It is complex due to the complicated geometry, but also to the biomechanics of this joint. Initially, three-dimensional scanning of a femur was attempted, but due to the fact that only the outer geometry could be obtained, this method was dropped. Computational methods have been used that based on identifying shades of gray on tomographic images and transposing them into geometries (surfaces). These surfaces processed with the Geomagic program were transformed into virtual solids in SolidWorks. In this program, bone components were assembled and pubic symphysis was modeled. Finally, the model was exported to Ansys where, based on normal walking loads, a finite element method simulation was performed. At the end of the paper interesting conclusions were highlighted.

Key words: Virtual hip, normal walking loads, pubic symphysis, virtual test, bone models.

1. INTRODUCTION

The hip joint is a complex structure consisting of bones covered with cartilage, muscles and their tendons, fascia and ligaments. It is a typical spherical joint with three axes of motion and has a great importance in statics and locomotion. In this joint, the femoral head and the acetabulum are joined.

The biomechanics of this important joint are also very important. In the biomechanics analysis, the contact between the bone components and muscle action is relevant.

Around the coxofemoral joint, the strongest muscle groups are placed: the pelvic muscles and a part of the thigh muscles, along with the abdominal and back muscles, which also participate in the swinging movements of the pelvis. The total number of muscles with action on the joint amounts to 54.

The pelvic and thigh muscles perform: Static contraction of the two body segments, the movements of the pendulum thigh against the trunk, the movements of the trunk against the fixed thigh (the spindle).

Thigh movements are complex. These can be reduced to the three fundamental torques of movement performed around the three main axes of the joint: 1) in the sagittal plane: the flexion (120°) and the extension (113°) around the axle transversally disposed; 2) in the front plane: abduction (40°) and adduction (10°) around a sagittal shaft; 3) inward rotation (36°) and outward rotation (13°) around a longitudinal axis.

Having the fixed point distal (on the fixed thigh), the muscles provide either trunk movements or balancing the pelvis while preserving trunk recurrence (by dynamic contraction), or stabilizing any baseline position on the fixed member (by static contraction).

The role of the pelvis as an intermediate segment, belonging to both the trunk and the inferior member, should be specified. From a biomechanical point of view, it performs the role of a mobile platform curving on the ends of the femurs and implanting the spine as a supporting body [1], [2].

2. THREE-DIMENSIONAL MODEL OF THE NORMAL HUMAN HIP JOINT

The purpose of this study is to obtain the three-dimensional models of the normal hip joint, as well as the atypical fixation for the use of these models in various virtual analyzes and experiments [2].

There are several computational methods that allow for three-dimensional hip joint models:

- a method based on three-dimensional scanning;
- a method based on obtaining virtual models from tomography or MRI images;
- a method that combines the two methods and involves different CAD (Computer Aided Design) techniques [3], [4], [5].

For 3D scanning, the 3DSYSTEMS CAPTURE 3D scanner shown in Fig. 1 was used [6], [7], [8].



Fig. 1 3D scanner used for a femur taken from a corpse.

It was also scanned three-dimensionally and a pelvis bone using Geomagic for SolidWorks software (Fig. 2).

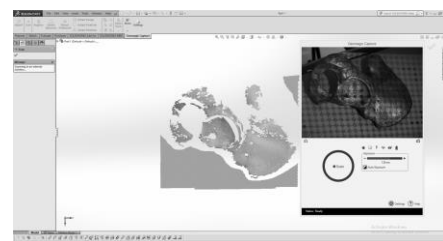


Fig. 2 Scanned surfaces of a pelvis bone.

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Finally, three-dimensional scanning was dropped, but some surfaces were used to virtual reconstruction of the hip joint. However, to achieve the virtual model of this important joint, several sets of CT images and InVesalius software have been used (Fig. 3).

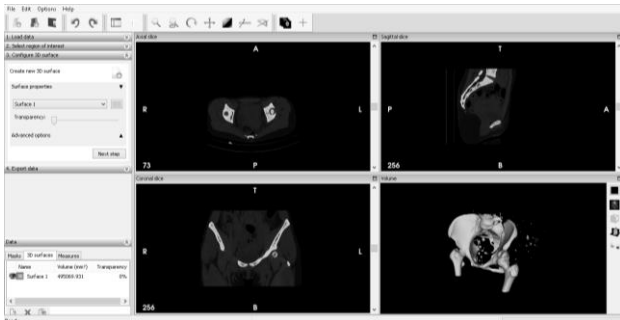


Fig. 3 The interface of InVesalius software.

The .stl format was imported into Geomagic software for processing. The interface of this program is shown in Fig. 4.

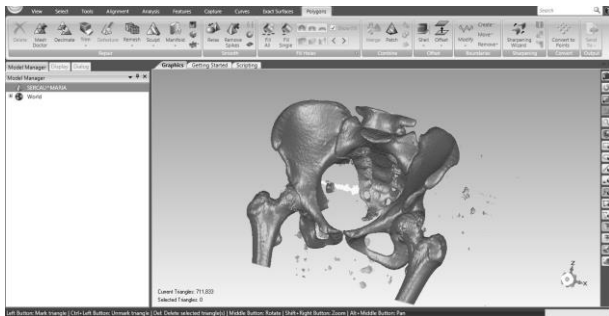


Fig. 4 The user interface of Geomagic software.

Models obtained from CT images are accompanied by elements and components that do not really exist, probably due to the reflection or refraction phenomena of the Roentgen rays. These elements can be removed using the capabilities of this program as can be seen in Fig. 5.

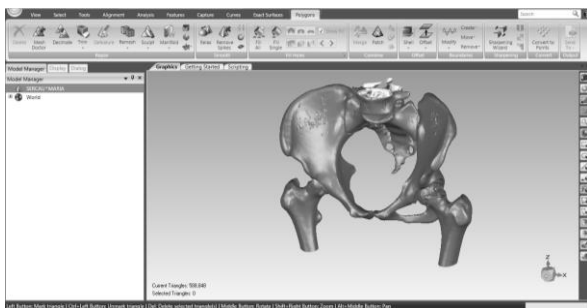


Fig. 5 The model of the hip after first operation in Geomagic software.

Due to the fact that SolidWorks software can not turn into virtual solids very large models with many "triangles" their number has been reduced, then some "smooth" techniques have been applied (Fig. 6).

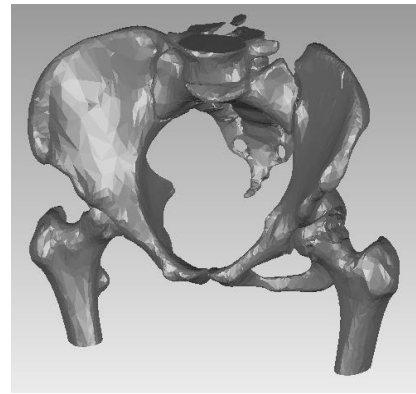


Fig. 6 The hip joint model after various operations applied in Geomagic.

Finally, the hip joint model was transferred to SolidWorks where it was automatically transformed into virtual solids (Fig. 7).

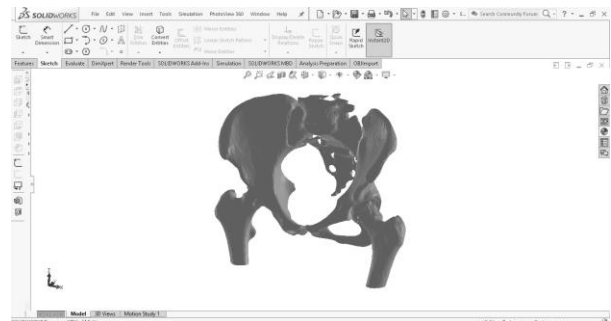


Fig. 7 The hip joint model in SolidWorks.

In parallel to these operations, a femur taken from a corpse was separately CT scanned. Using similar methods and techniques, a model for the femur presented in Fig. 8 was obtained.



Fig. 8 The virtual model of the femur bone (different views and section).

From the initial hip joint model, the right iliac bone was removed (Fig. 9), and the left iliac bone was obtained by mirroring operations in SolidWorks.

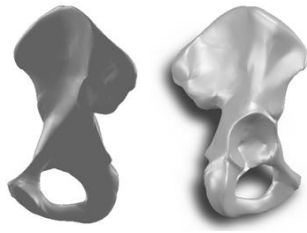


Fig. 9 Right iliac bone model (two different views).

These virtual bone components were assembled in the Assembly of SolidWorks module. Also pubic symphysis has been modeled (Fig. 10).

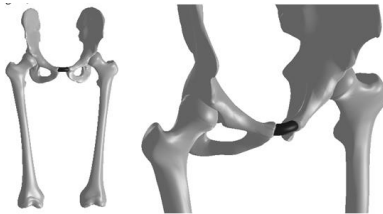


Fig. 10 The virtual hip with pubic symphysis (red).

3. SIMULATION USING FINITE ELEMENT METHOD OF HUMAN HIP FOR NORMAL WALKING LOAD

This hip joint model was transferred to a very well-known finite element analysis program, Ansys Workbench with which SolidWorks has a common transfer interface (Fig. 11).

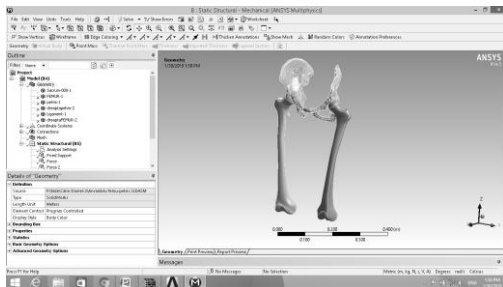


Fig. 11 The human hip joint model in Ansys Workbench.

To obtain a correct simulation, a series of data has been used on the materials to be attached to the model components. Table 1 presents these data that led to the definition of new materials in Engineering Data Sources.

Table 1

Materials used in simulation with the main mechanical characteristics.

Material	Component	Density [kg/m ³]	Elastic modulus Young [N / m ²]	Poisson's coefficient
Cortical bone	Femur, pelvis	1400	1·10 ¹⁰	0.3
Ligament	Pubic symphysis	950	1.1 10 ⁹	0.42

Initially, the model was divided into finite elements as shown in Fig. 12.

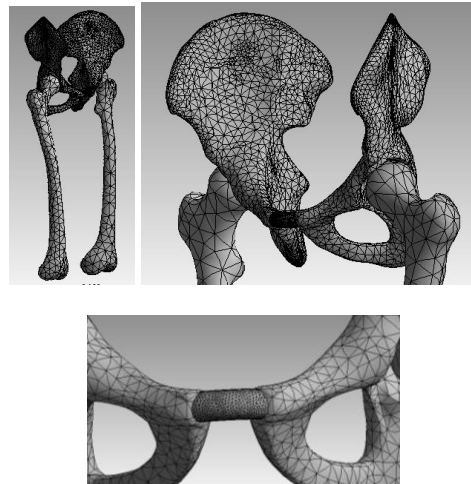


Fig. 12 The finite elements structure of the virtual hip.

Using the results from previous cinematic simulations based on the complete reconstruction of the human locomotor in the SolidWorks Motion module, the loads presented in Fig.13 and 14 [1], [4], [5].

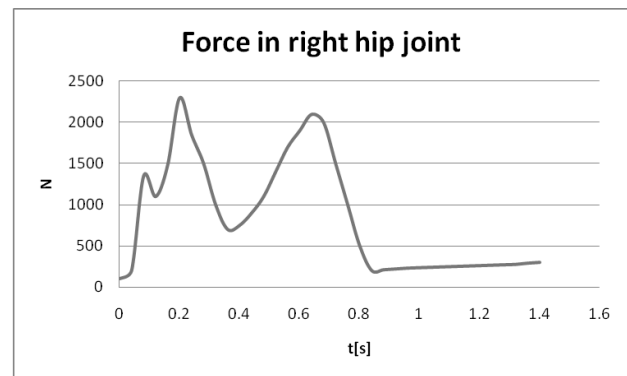


Fig. 13 The force evolution in right hip.

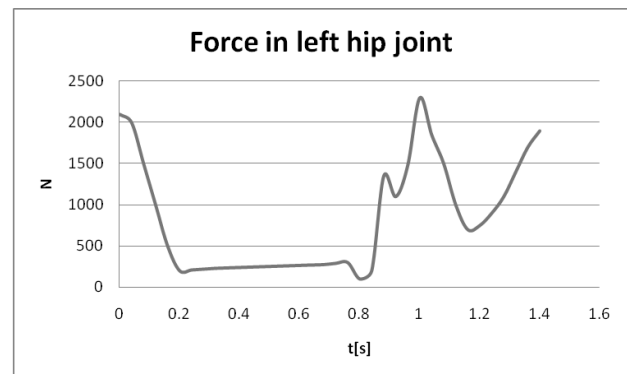


Fig. 14 The force evolution in left hip.

After running the application, were obtained results maps according to the von Mises criterion. Fig. 15 and 16 show deformation map, strain map and stress map.

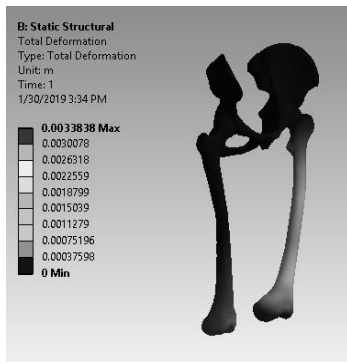


Fig. 15 The total deformation map.

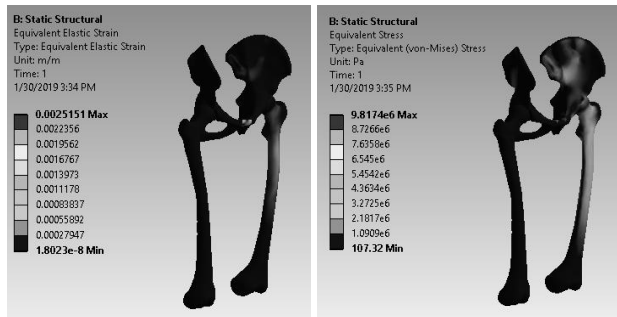


Fig. 16 The equivalent strain and stress maps.

4. CONCLUSIONS

Analysing the obtained results in this paper, the following conclusions were drawn:

- using parameterized CAD programs can be modeled complicate biological systems;
- applying CAD methods and medical imaging techniques can lead to personalized models at the patient's level. These methods can do even more, bringing these virtual models to the virtual reality where medical diagnosis can be sensitively improved;
- from the analysis of the deformation map it is found that the maximum value is 3.38 mm, this being recorded in the femoral bottom area;
- from the analysis of the equivalent strain map it was found that the maximum value is 0.002515 in the pubic symphysis area;
- analyzing the stress map, obtained by the von Mises criterion, it was observed that the maximum value is $9.81 \cdot 10^6$ Pa, which is found in the femoral diaphysis area.

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